SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

   BE IT KNOWN THAT WE, Sung Uk Moon, a citizen of
Korea residing at Yokosuka-shi, Kanagawa Japan,
Takahiro Hayashi, a citizen of Japan residing at Yokosuka-shi,
Kanagawa Japan and Toshiyuki Futakata, a citizen of Japan
residing at Yokosuka-shi, Kanagawa Japan have invented certain
new and useful improvements in

MODULATION AND DEMODULATION BASED ON HIERARCHICAL MODULATION

Of which the following is a specification:-

MODULATION AND DEMODULATION BASED ON HIERARCHICAL MODULATION

BACKGROUND OF THE INVENTION

5   The present invention generally relates to modulation
and demodulation in digital data transmission, and more
particularly to a modulation and demodulation technique
capable of dealing with multiple types of modulation based
on hierarchical modulation.

10

       In recent radio communications, digital modulation
techniques are employed in, for instance, cellular phone
networks, BS television broadcast, and other digital
communication networks. Known modulation techniques used in
15   digital mobile communications include quadrature phase shift
keying (QPSK) and quadrature amplitude modulation (QAM).

       Quadrature phase shift keying (QPSK) is a modulation
technique that uses two carriers out of phase by 90 degrees
(that is, quarternary signal states), allowing 2 bits/symbol
20   transmission. FIG. 1 is a QPSK signal constellation, in
which the in-phase component and the quadrature component of
the QPSK modulation signal are expressed in the phase plane
defined by the I-axis (representing the real number) and the
Q-axis (representing the imaginary number). The signal
25   constellation is also called "signal diagram". In QPSK
modulation, modulation signals with four different phases
are arranged at the vertexes of a square. In other words,
the transmission signal is represented by one of the four
phases.
30   Another type of QPSK modulation is pi/4-shift QPSK,
which is derived from the above-described QPSK and used in
personal digital cellular (PDC) phones based on the second
generation mobile communications standard. With pi/4-shift

QPSK, the phase of the carrier rotates by pi/4 per symbol, providing quarternary signal states.

In W-CDMA in FDD mode, which is one of the radio transmission protocols used in the third generation cellular systems based on the International Mobile Telecommunications-2000 (IMT-2000) standard, BPSK (binary phase shift keying) is used for uplink data modulation, while QPSK is used for downlink data modulation. In TDD mode, QPSK is employed for data modulation on both uplink and downlink.

Another known modulation technique is 16-QAM (quadrature amplitude modulation), which allows 4 bits/symbol data transmission using a combination of phase and amplitude of the carrier representing one of sixteen (16) four-bit patterns. FIG. 2 is an example of a 16-QAM signal constellation. With 16-QAM, four bits (16 patterns) of an input sequence are divided into four 2-bit patterns. The two carriers out of phase by 90 degrees are amplitude-modulated in the respective four signal states, and synthesized. The constellation plotted after the amplitude modulation is shown in FIG. 2. The divisions on the I-axis and the Q-axis are -0.9487, -0.3162, 0.3162, and 0.9487. Comparing the 16-QAM with the above-described QPSK under the same transmission rate, the occupied band-width of 16-QAM is narrower than that of QPSK. This means that 16-QAM is more effective to realize high-speed digital data transmission. However, 16-QAM is easily influenced by fading, which is the phenomenon of sharp fluctuation in intensity level of a radio wave due to environmental change including time and the distance between the transmitter and the receiver. The 16-QAM is mainly used for digital MCA (telecommunications business).

Since the above-described two modulation techniques,

QPSK and 16-QAM, are used in digital mobile telecommunications, hardware capable of dealing with these two modulation techniques is desirable. Such hardware is advantageous for both users and manufacturers, reducing the

5   cost of components and the space for accommodating the hardware, while improving operability. From this standpoint, JPA 9-27426 proposes a demodulation technique for demodulating both QAM modulation signals and QPSK modulation signals in one system.

10   However, in spite of the existence of multiple modulation techniques used in digital telecommunications, the transmission ability and the receiving ability are not always consistent with each other. If a receiver is capable of dealing with only QPSK modulation signals, 16-QAM

15   modulation signals transmitted from a transmitter cannot be demodulated. To overcome this problem, a 16-QAM demodulator has to be furnished in the receiver, in addition to the QPSK demodulator, or alternatively, a system proposed in JPA 9-275426 is required. The former method causes the circuit

20   scale and the cost to increase because an extra demodulator has to be added to the receiver. The latter method provides two independent signal paths, one functioning as a QAM demodulator when receiving a QAM modulation signal, and the other functioning as a QPSK demodulator when receiving a

25   QPSK modulation signal. One of these two demodulation types is selected depending on the modulation type of the received signal. Accordingly, it is essential to furnish the functions of a QAM demodulator and a QPSK demodulator in the circuit structure.

30

SUMMARY OF THE INVENTION

The present invention is conceived to overcome the

above-described problems, and it is an object of the invention to provide a modulation/demodulation technique that allows received data to be demodulated according to the demodulation ability of the receiver even if the demodulation ability on the receiving side is not totally consistent with the modulation functions of the transmission side apparatus.

To achieve the object, in one aspect of the invention, a modulation device is furnished with a hierarchical modulation function. To be more precise, the modulation device comprises a modulation unit that modulates data in a hierarchical manner using multiple types of modulation techniques, and a transmission unit that transmits the hierarchically modulated data.

The modulation device further comprises a sampling pattern generating unit that generates a sampling pattern for each of the modulation techniques. The sampling pattern defines a sampling space for quantizing said data in accordance with each of said modulation techniques. In this case, the modulation unit modulates said data in the hierarchical manner using a digital signal sampled based on the sampling pattern.

The sampling pattern defines the sampling space of a carrier used in, for example, multi-phase phase shift keying or multi-value quadrature amplitude modulation.

Preferably, the transmission unit transmits the sampling pattern together with the hierarchically modulated data.

In another aspect of the invention, a demodulation device that receives and demodulates hierarchical modulation data is provided. The demodulation device comprises a receiving unit that receives hierarchical modulation data having been subjected to hierarchical modulation using

multiple types of modulation techniques, and a demodulation
unit that demodulates the hierarchical modulation data using
a demodulation technique corresponding to a specific
hierarchy of the hierarchical modulation data.

5   Preferably, the demodulation unit is furnished with
multiple types of demodulation techniques, and in this case,
the demodulation device further comprises a demodulation
type selection unit that selects one of the demodulation
techniques to be used for demodulation of the hierarchical

10   modulation data. Accordingly, the hierarchical modulation
data are demodulated using the selected one of the
demodulation techniques.

The demodulation type selection unit selects said one
of the demodulation techniques in accordance with, for

15   example, the traffic of a service area, the propagation
environment, or a service request.

Preferably, the receiving unit receives a sampling
pattern used for the hierarchical modulation, together with
the hierarchical modulation data. In this case, the

20   demodulation unit demodulates the hierarchical modulation
data using the sampling pattern.

With the above-described arrangements, transmission
data are modulated in a hierarchical manner using multiple
types of modulation techniques. The demodulating device on

25   the receiving side does not have to be furnished with all
the demodulation functions corresponding to the modulation
techniques on the transmission side, but may have a single
demodulation function corresponding to a specific hierarchy
of the hierarchical modulation data. Consequently, the

30   received data are appropriately demodulated even if the
modulation ability on the transmission side and the
demodulation ability on the receiving side are not totally
consistent with each other. When the receiving side

demodulating device is furnished with two or more types of demodulation functions, the optimum demodulation type is selected, taking into account the propagation environment and other factors. Consequently, telecommunications can be

5   maintained without undesirable disconnection even if the propagation environment abruptly changes.

BRIEF DESCRIPTION OF THE DRAWINGS

10   FIG. 1 is an example of a QPSK signal constellation;

FIG. 2 is an example of a 16-QAM signal constellation;

FIG. 3 illustrates the structure of the modulation and demodulation device according to an embodiment of the invention;

15   FIG. 4 is a block diagram of the modulator included in the modulation and demodulation device shown in FIG. 1;

FIG. 5 is a block diagram of the demodulator included in the modulation and demodulation device shown in FIG. 1;

FIG. 6 is a graph showing an example of hierarchical

20   modulation carried out by the modulator shown in FIG. 4;

FIG. 7 is a table of a set of 16-QAM modulation signals;

FIG. 8 is a table of sampled transmission data modulated by 16-QAM;

25   FIG. 9 illustrates correlation between 16-QAM modulation signals and QPSK modulation signals having been subjected to 16-QAM/QPSK hierarchical modulation; and

FIG. 10 is a table of the demodulation results of 16-QAM modulation signals using the QPSK demodulation technique.

30

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described in detail

in conjunction with the attached drawings. FIG. 3 illustrates a modulation and demodulation device (referred to as a MODEM), which comprises a modulator and a demodulator, according to an embodiment of the invention.

5   Modulation and demodulation device 100 (Modem A) and modulation and demodulation device 200 (Modem B) are located at physically separate positions, and carry out data transmission via wireless telecommunications. The modulation and demodulation devices 100 and 200 (Modem A and Modem B)

10   have the same structure, and they include modulators 10, 20, and demodulators 11, 21, respectively. Each of the modulators 10 and 20 modulates transmission data in a hierarchical manner. Each of the demodulators 11 and 21 demodulates a received signal according to its receiving

15   ability. Since the structures of the modulation and demodulation devices 100 and 200 are the same, the detailed structure thereof will be explained referring to one of these two devices, specifically, Modem A.

        FIG. 4 illustrates the modulator 10 of the modulation

20   and demodulation device 100 (Modem A) shown in FIG. 3.

        The modulator 10 comprises a sampling pattern generating unit 1, a modulation unit 2, and a transmission unit 3. The sampling pattern generating unit 1 generates sampling patterns according to modulation types, and

25   supplies the sampling patterns to the modulation unit 2. The sampling pattern represents information about the sampling period for acquiring discrete data along the temporal axis and information about sampling space (or interval) for acquiring discrete data (i.e., quantization) in the

30   amplitude direction. The sampling pattern generating unit 1 is capable of generating a sampling pattern according to a modulation type. The modulation unit 2 converts analog transmission data into digital data based on the sampling

pattern supplied from the sampling pattern generating unit 1, and modulates the sampled digital data in a hierarchical manner. The hierarchical modulation will be explained later. The transmission unit 3 converts the modulation signal of

5   the transmission data having been subjected to the hierarchical modulation into a radio wave, and outputs the radio frequency transmission signal.

FIG. 5 is a block diagram of the demodulator 11 of the modulation and demodulation device 100 (Modem A).

10 The demodulator 11 comprises a receiving unit 4, a demodulation type selection unit 5, and a demodulation unit 6. The receiving unit 4 carries out RF processing, such as frequency conversion, on the signal received via a transmission medium (in this example, a wireless network),

15 and supplies the processed signal to the demodulation unit 6. The demodulation type selection unit 5 selects a demodulation type from the demodulation functions (or available demodulation types) of the demodulation unit 6, and designates the demodulation type for the demodulation

20 unit 6. The demodulation unit 6 demodulates the received signal using the selected demodulation type to acquire the data.

In this manner, data are transmitted between the modulation and demodulation device 100 (Modem A) and the

25 modulation and demodulation device 200 (Modem B). Details of hierarchical modulation carried out on the transmission side are described below, assuming that signals are transmitted from the modulation and demodulation device 100 (Modem A) to the modulation and demodulation device 200 (Modem B).

30

(Operations of Modulator 10 of Modem A on Transmission Side)

The modulator 10 of the transmission-side Modem A carries out hierarchical modulation of transmission data for

multiple modulation types. In this example, the multiple modulation types include 16-QAM, which is an example of multi-value QAM, and QPSK, which is an example of multi-phase PSK. Since multiple modulation techniques, namely, 16-QAM and QPSK, are used, the sampling pattern generating unit 1 generates sampling patterns for 16QAM and QPSK. The sampling pattern for 16-QAM causes the transmission data to be sampled at one of sixteen possible states separated by a prescribed sampling space (quantization in the amplitude direction) every sampling period (Bt). The sampling pattern for QPSK causes the transmission data to be sampled at one of four possible states every sampling period (Bt).

FIG. 6 illustrates an example of hierarchical modulation carried out by the modulation unit 2, which is obtained by sampling the transmission data using a 16-QAM sampling pattern (sampling pattern 1) and a QPSK sampling pattern (sampling pattern 2), and by modulating the sampled data. In FIG. 6, the curve A represents analog information (for example, voice or sound) as transmission data. If digital data are transmitted based on QAM modulation in which continuous analog data are sampled at a sampling period along the horizontal axis (or time axis) and quantized at a sampling interval along the vertical axis, the restoration accuracy of the original data is improved as the sampling interval along the vertical axis becomes shorter. In other words, the smaller the sampling space in the amplitude directions, the more completely the continuous temporal (analogue) signal can be restored from the sampling values.

In FIG. 6, digital transmission data B1-B16 (4-bit data) sampled and quantized based on the 16-QAM sampling pattern (sampling pattern 1) are represented by dark circles. FIG. 7 illustrates the correlation between the constellation

points of the 16-QAM signal constellation shown in FIG. 2 and the modulation signals. For the digital data B1-B16, modulation signals shown in FIG. 8 are acquired from the 16-QAM signal constellation of FIG. 2 and the correlation of FIG. 7. The modulation signals correlated to the sampling data B1 through B16 in FIG. 8 are mapped to the constellation points indicated by dark circles in FIG. 9. For example, the modulation signal (-0.9487-0.9487i) of 16-QAM signal (1111) for sampling data B1 is mapped to constellation point (1111) indicated by the dark circle in the third quadrant. Similarly, the modulation signal (-0.9487-0.3162i) of 16-QAM signal (1110) for sampling data B2 is mapped to constellation point (1110) indicated by the dark circle in the third quadrant. The same applies to the 16-QAM signals of B3 and the subsequent sampling data.

Returning to FIG. 6, digital transmission data (2-bit data) B1-B16 sampled and quantized based on the QPSK sampling pattern (sampling pattern 2) are represented by white squares. Since QPSK modulation uses four possible states produced by two carriers out of phase by 90 degrees, the QPSK sampling pattern contains information required to sample the transmission data at four sampling states (00, 10, 11, 01). The modulation phases for these four states are indicated below.

(00): $\pi/4$

(10): $3\pi/4$

(11): $-3\pi/4$

(01): $-\pi/4$

When carrying out hierarchical modulation to these four signal states and mapping into the same coordinate plane as the 16-QAM signal states, the signal constellation shown in FIG. 9 is obtained. FIG. 9 shows the correlation between 16-QAM constellation points and QPSK constellation points

during the 16-QAM/QPSK hierarchical modulation performed by
the modulator 10. Four states (0000, 0001, 0010, 0011) of
16-QAM indicated by dark circles in the first quadrant
correspond to a single state (00) in the QPSK signal space,
5   which is indicated by a white square in the first quadrant.
This two-bit data are mapped to the modulation phase of $\pi/4$.
    Similarly, four states (1000, 1001, 1010, 1011)
indicated by dark circles in the second quadrant correspond
to a single state (10) in the QPSK signal space, and this
10   two-bit data are mapped to the modulation phase of $3\pi/4$.
Four states (1100, 1101, 1110, 1111) indicated by dark
circles in the third quadrant correspond to a single state
(11) in the QPSK signal space, and this two-bit data are
mapped to the modulation phase of $-3\pi/4$. Finally, four
15   states (0100, 0101, 0110, 0111) indicated by dark circles in
the fourth quadrant correspond to a single state (01) in the
QPSK signal space, and this two-bit data are mapped to the
modulation phase of $-\pi/4$.
    The data in the 16-QAM space and the data in the QPSK
20   space are mapped in a hierarchical manner as a layered
structure having the same coordinate axes. This operation is
referred to as hierarchical modulation of transmission data
in this embodiment.

25   (Operations of Demodulator 21 of Modem B on Receiving Side)
    Next, the operations of the demodulator 21 of the
modulation and demodulation device 200 (Modem B) for
demodulating the 16-QAM/QPSK hierarchical modulation signal
transmitted from Modem A will be explained. The demodulator
30   21 has the same structure as demodulator 11 shown in FIG. 5.
When the receiving unit 4 of the demodulator 21 receives the
hierarchical modulation signal via the wireless
telecommunication network, the demodulation unit 6

demodulates the received signal as it is using the 16-QAM demodulation technique if the demodulator is furnished with a 16-QAM demodulation function. On the other hand, if the demodulation unit 6 has only a QPSK modulation ability,

5 without being furnished with the 16-QAM demodulation function, then the received 16-QAM/QPSK hierarchical modulation signal is demodulated in the following manner based on the QPSK modulation technique.

The demodulation unit 6 determines to which quadrant

10 the 16-QAM layer of the received signal belongs, and finds the corresponding QPSK state in the determined quadrant, prior to carrying out QPSK demodulation. For example, if the signal of the 16-QAM layer represents any one of the four states (0000, 0001, 0010, 0011) of the first quadrant, the

15 modulator 6 takes the first two bits (00 in this example) from the bit sequences of the received 16-QAM signal, and finds a single state (00) of QPSK layer mapped in the first quadrant, as indicated by the white square in FIG. 9. The demodulation unit 6 performs the same operation and

20 successively carried out QPSK demodulation for all of the sampled data B1 through B16. The demodulation result of the 16-QAM modulation signal using the QPSK demodulation technique is shown in FIG. 10. The demodulation unit 6 outputs the QPSK demodulation results to the next processing

25 stage.

Since the transmission data have been modulated in a hierarchical manner using multiple types of modulation techniques, the modulation signal can be demodulated on the receiving side as long as the receiving side demodulator has

30 a demodulation ability corresponding to at least one of the multiple modulation types. This means that even if the modulation/demodulation abilities on the transmission side and the receiving side are not totally consistent with each

other, transmission data can be demodulated appropriately
according to the demodulation ability of the receiving side
modulator, without increasing the circuit scale.

In the above-described example, it is assumed that the
demodulation unit 6 of the receiving side demodulator 21 has
only demodulation ability for a QPSK signal. However, the
present invention is not limited to this example. For
example, the modulation unit 6 may have two or more types of
demodulation functions, and the optimum demodulation type
may be selected from the multiple types of demodulation
techniques. In this case, the demodulation type selection
unit 5 shown in FIG. 5 is used to select the optimum
demodulation type.

The demodulation type selection unit 5 manages the
demodulation ability of the demodulation unit 6, and selects
the optimum demodulation type for the demodulation unit 6,
taking into account the propagation environment, the service
request, and other factors. The demodulation unit 6 operates
in accordance with the selected demodulation type supplied
from the demodulation type selection unit 5. For instance,
if the demodulation unit 6 has a 16-QAM demodulation
function and a QPSK function, then the demodulation type
selection unit 5 selects the most appropriate one at the
time of receiving the modulation signal, taking into account
the traffic of the service area, the propagation environment,
the service request, and other factors.

Especially, under the mobile telecommunication
environment in which the modems on the transmission side and
the receiving side are connected via a wireless
telecommunications medium, with one of the modems moving,
the influence of fluctuation due to fading has to be taken
into account when selecting the demodulation type. For
example, when the influence of the instantaneous fading

fluctuation is large, the QPSK demodulation type with a smaller number of modulation signal states is generally selected, and the received data are demodulated so as to satisfy the prescribed quality to the greatest extent

5   possible. On the other hand, under the propagation environment in which the influence of the instantaneous fading fluctuation is small, the 16-QAM demodulation type with a greater number of modulation signal states is selected because the utilization efficiency per unit

10   frequency is superior. In this case, the received data are demodulated aiming at higher transmission quality. In this manner, even if the transmission quality is degraded due to a change in the propagation environment, the optimum demodulation type is selected in accordance with the current

15   conditions. Consequently, the telecommunications can be maintained between the transmission side and the receiving side, without interruption or disconnection. Furthermore, by selecting the demodulation type while taking the traffic of the service area and the service request into account, the

20   service quality is improved.

In the above-described embodiment, the hierarchical modulation signal alone is transmitted from the modulator 10 of the modem A to the demodulator 21 of the receiving side modem B. However, the sampling pattern may also be

25   transmitted to the modem B, together with the hierarchical modulation signal. In this case, the demodulator 21 of the modem B can demodulate the modulation signal using the sampling pattern. Accordingly, the modulation unit 6 of the receiving side modulator 21 does not have to have multiple

30   types of demodulation functions, but has only a modulation function of a specific hierarchy.

Although the present invention has been described using an example of data transmission via a wireless

telecommunication network, the present invention can be applied to data transmission via other transmission media, such as a cable. When data transmission is carried out via a wireless telecommunications network, the modulation and

5   demodulation device 100 (Modem A) is installed in a mobile terminal, such as a cellular phone, and the modulation and demodulation device 200 (Modem B) is installed in a base station, for example.

In the above-described embodiment, hierarchical

10   modulation is explained using 16-QAm and QPSK. However, the present invention can be applied to any multi-value QAM exceeding sixteen signal states (for example, 128 or 256 states), and any multi-phase QPSK, such as $\pi/4$-shift QPSK or BPSK.

15   Although, the present invention has been described using a modulation and demodulation (MODEM) device, providing a modulation device and a demodulation device separately is also within the scope of the present invention.

Since transmission data are modulated by multiple types

20   of modulation techniques in a hierarchical manner before the data are transmitted, the demodulator of the receiving side device can demodulate the received data as long as it has at least one of the demodulation functions corresponding to a specific hierarchy of the multiple demodulation types. If

25   the demodulator of the receiving side device has two or more types of demodulation functions, the optimum demodulation type can be selected according to the propagation environment or other factors.

The modulation unit 2 of the modulator 10 (and 20) can

30   carry out hierarchical modulation. The transmission unit 3 of the modulator 10 (and 20) has a function of transmitting a modulation signal and a sampling pattern. The sampling pattern generating unit 1 generates a sampling pattern for

each of multiple types of modulation techniques. The
demodulation unit 6 of the demodulator 11 (and 21)
demodulates the hierarchical modulation signal received at
the receiving unit 4. The demodulation type selection unit 5

5   selects the optimum demodulation type corresponding to one
of the multiple types of modulation techniques. The
demodulation unit 6 can also demodulate the hierarchical
modulation signal based on the sampling pattern transmitted
from the modulator 10.

10   In conclusion, since transmission data are modulated
with multiple types of modulation techniques in a
hierarchical manner, the receiving side demodulator can
demodulate the modulation signal as long as it is furnished
with at least a single demodulation function corresponding

15 to a specific hierarchy of the modulation signal. Even if
the modulation/demodulation abilities on the transmission
side and the receiving side are not totally consistent with
each other, data can be appropriately demodulated according
to the demodulation ability of the receiving side

20 demodulator, without requiring the circuit scale to be
increased. When the receiving side demodulator has two or
more types of demodulation functions, the optimum
demodulation type can be selected in accordance with the
circumstances, such as the propagation environment.

25 Consequently, telecommunications can be maintained without
disconnection even if the communication quality is degraded
due to change in propagation environment.

     This patent application is based on and claims the
benefit of the earlier filing date of Japanese Patent

30 Application No. 2002-291571 filed October 3, 2002, the
entire contents of which are hereby incorporated by
reference.